CROP WATER REQUIREMENTS IN ARID CLIMATE OF KACHHI PLAIN, BALOCHISTAN

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ABSTRACT: Global demands for food & fiber are increasing, necessitating efficient management of the irrigated water. Vast-uncultivated but otherwise fertile lands in Baluchistan, Pakistan attract the authorities to develop the land for agriculture through irrigation. Kachhi plains are one of such areas that will be provided canal water through a gravity canal system off-taking from Indus river at Taunsa Barrage. Efficient use of water especially in arid climates requires good estimates of crop water requirements (CWR). Physical based methods of estimating crop water requirement including the Radiation-Resistance based methods take into account the energy radiated from various sources and the atmospheric resistance depending on air circulation and humidity. This study employs a radiation-resistance based Penman Monteith Equation (Allen *et al*., 1998) through a spread sheet based tool and CROPWAT software to estimate the crop water requirements in Kachhi Plains, the study area. The study compares the reference crop evapotranspiration with four other well known methods. Meteorological data namely rainfall, temperature, humidity, actual sunshine hours of the closest meteorological station i.e. Jacobabad station is used for the study. Crop coefficients are calculated using FAO guidelines. Total water requirement for Wheat is estimated as 380 mm, while that for Cotton is 928 mm. Crop water requirement calculated by the spreadsheet matches well with that from CROPWAT. The result differs by 3 % from the crop water requirements estimated/used by the feasibility report of the Kachhi Canal. Staggering of major crops (wheat, cotton) have been incorporated while computing the CWR. The study can be used for optimization of the cropping pattern and can further be extended by estimation of crop water requirement using lysimeter in the study area. It can also be used to study the impact analysis of meteorological data on the crop water requirement.

Key words: Crop Water Requirement, CROPWAT, Evapotranspiration, Kachhi Canal, Pakistan.

INTRODUCTION

Balochistan, the largest province of Pakistan, is located in arid to semi-arid climatic zone. Areal extent of Balochistan is 46% of Pakistan while its population is just 8% of Pakistan. Vast-uncultivated but otherwise fertile lands in Balochistan, attracted the authorities to develop the land for agriculture through irrigation. Kachhi plains are one of such areas that will be provided canal water through a gravity canal system off-taking from Indus river at Taunsa Barrage. Vast barren lands in this area can be brought under cultivation by augmented supplies of the cnal under construction. Kachhi plain is located on Right bank of Indus River in eastern Balochistan (Figure-1). Current yield of all the crops in Kachhi plain is too low because of limited ground water and surface run-off for irrigation. The total area in Kachhi plain is about 404,6 thousands hectares; out of this 288.5 thousands hectares are cultivatable land (Wapda, 2000).

Efficient use of water, especially in arid climates, requires good estimates of crop water requirements (CWR). Traditionally CWR has been estimated using empirical methods, such as Pan-Evaporation method, Blaney Criddle, Hargreaves, and Pristley & Tayler etc. equations (Maidement, 1993; Venturinia at al., 2011). Radiation-resistance based methods take into account the energy radiated from various sources and the atmospheric resistance depending on air circulation and humidity. Such physically based approaches are gaining popularity for better modeling of the nature employing the physics of various phenomenon involved in processes.

This study employs a radiation-resistance based Penman Monteith Equation (Allen *et al*., 1998) through a spreadsheet based tool to estimate reference crop evapotranspiration (ET_o) and crop evapotranspiration (ET_c). The result of spreadsheet are compared with a well established software's results. CROPWAT software, developed by Food and Agriculture Organization (FAO) is used for this purpose to estimate the ET_o and ET_c in Kachhi Plain, the study area. The study further compares the reference crop evapotranspiration (ETo) with four other well known methods; namely Blaney Criddle, Hargrieves, Pristley & Tayler, and Kimberley methods, and proposes the suitable methods to be utilized.

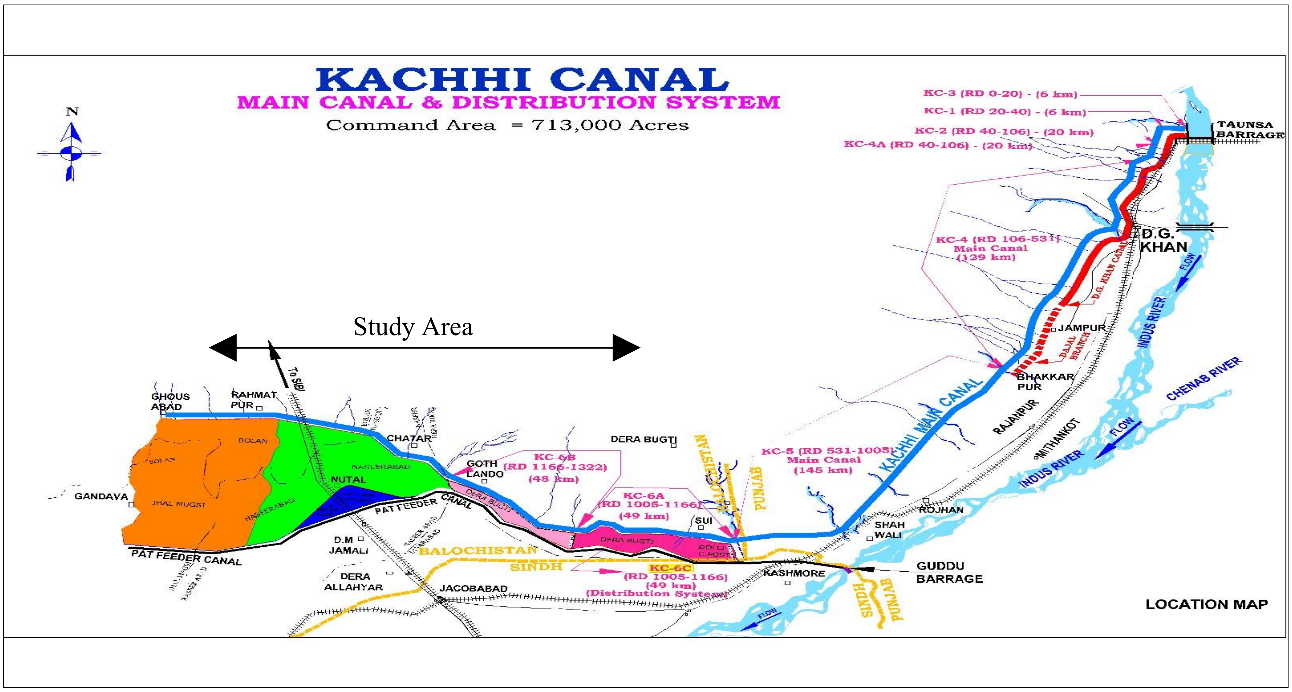

Figure-1, Layout of Kachhi Canal and Its Command Area (Wapda, 2000).

Various studies have been carried out to estimate crop evapotranspiration for Indus basin as a whole, and its parts. Some important ones are worth to be mentioned. (Ullah *et al*., 2001) computes different components of potential crop water demand at the canal command level in Indus Basin. Major contribution is update of water demand based on several years of climate data, which improves the estimation of reference evapotranspiration for developing refined crop coefficients based on the latest cropping patterns.

(Abbas *et al*., 2006) describes a holistic approach to understand the limitations of current irrigation practices and to propose strategies for gaining potential benefits of crop per drop. Post Indus Water Treaty's expansion of uses in irrigation water terrifically ignored the water sustainability and unpredicted drought scenarios that would severely affect the crop production. The severity of recurring droughts and manifold increased cropping intensity requires analysis of irrigation practices to devise adaptive strategies against highly variable climate change.

(Shakir *et al*., 2010) estimated reference evapotranspiration (ET_o), and irrigation requirements for different crops cultivated according to existing cropping pattern. The comparison of actual canal water supplies and crop water requirements indicated an annual shortage of more than 40% which, may reduce slightly if allocated water supplies according to Water Apportionment Accord-1991, can be ensured. The possible options for better water management in the UCC command area to optimize the crop yields are presented, and it is recommended to look into demand side management including canal lining and On Farm Water Management practices.

CROPWAT (FAO, 2011) is a computer program, developed by Food and Agriculture Organization (FAO), for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. Calculation procedures used in CROPWAT are based on the FAO publications of the Irrigation and Drainage series, FAO-56 (FAO, 2011). Current study has selected this well known software to verify the results of the spreadsheet based software/tool.

MATERIALS AND METHODS

Kachhi Plain covering an area of about 0.4046 millions Hectares falls in the eastern side of Balochistan. Its global location is between 27^o-50´ to 29^o-25´ North and 67^o-15´ to 69^o-15´ East (Figure-1). The climate is arid with mean monthly temperatures ranging from 13^oC to 50^oC over the year. Average rainfall, humidity, sunshine hours as reported by FAO for the nearby station Jacobabad) are shown in Table 1. The results of ET_o computed by spread sheets are compared with results of ET_o calculated by CROPWAT. Crop evapotranspiration ET_c are calculated, using Equation 2, for each crop (Figure 2, Figure 3) to be grown in this area. Crop coefficient (Kc) for each crop are calculated using FAO guideline (Allen *et al*., 1998), and the corresponding correction as depicted in equations 3, 4 and 5.

Reference Crop Evapotranspiration (ET_o): The permutation of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to as evapotranspiration (ET). The evapotranspiration rate from a reference surface is called the reference crop evapotranspiration and is denoted as ET_o. The reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sm^{-1} and an albedo of 0.23. The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground. The fixed surface resistance of 70 sm^{-1} implies a moderately dry soil surface resulting from about a weekly irrigation frequency (Allen *et al*., 1998). Reference crop evapotranspiration ET_o are estimated from Penman equation. The calculation procedures of all data required for the calculation of ET_o by means of the FAO Penman-Monteith equation (eq.1) are discussed here.

$$ET_0 = \frac{0.408\ \Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)} \quad \text{......(1)}$$

where:

ET_o = reference evapotranspiration [mm day^{-1}],

R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}],

G = soil heat flux density [MJ m^{-2} day^{-1}],

T = air temperature at 2 m height [°C],

U_2 = wind speed at 2 m height [m s^{-1}],

e_s = saturation vapour pressure [kPa],

e_a = actual vapour pressure [kPa],

e_s - e_a = saturation vapour pressure deficit [kPa],

Δ = slope of vapour pressure curve [kPa $°C^{-1}$],

γ = psychrometric constant [kPa $°C^{-1}$].

Crop Evapotranspiration (ET_c): The standard conditions for the calculations of ET_o refer to crops grown in large fields under excellent agronomic and soil water conditions. The crop evapotranspiration varies distinctly from the reference evapotranspiration (ET_o) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The effects of characteristics that distinguish field crops from grass are integrated into the crop coefficient (K_c). In the crop coefficient approach, crop evapotranspiration is calculated by multiplying ET_o by K_c.

$$ET_c = K_c . ET_o \quad \text{............ (2)}$$

where:

ET_c = crop evapotranspiration [mm day^{-1}],

K_c = crop coefficient [dimensionless],

ET_o= reference crop evapotranspiration [mm day^{-1}].

Tabulated K_c Values: FAO's Irrigation and Drainage Paper No.-56 (Allen *et al*., 1998) provide the four distinct growth stages and the total growing period for various types of climates and locations. Average crop coefficients ($K_{c\ ini}$, $K_{c\ mid}$ and $K_{c\ end}$) and mean maximum plant heights for non stressed, well-managed crops in subhumid climates (RH_{min}= 45%, and U_2 =2 m/s) for use with the FAO Penman-Monteith ET_o are given in Table-2. Various corrections to be applied on these base values are as below.

Determination of $K_{c\ ini}$:

$$K_{cini} = f_w K_{cini(Tab)} \quad \text{................ (3)}$$

where:

f_w = the fraction of surface wetted that depends on method of irrigation and varies between 0 and 1 (taken as 1 for this study for basin irrigation), $K_{c\ ini\ (Tab)}$ = the value for $K_{c\ ini}$ from Table-2.

Crop Coefficient for the Mid-season Stage ($K_{c\ mid}$): For specific adjustment in climates where RH_{min} differs from 45% or where U_2 is larger or smaller than 2.0 m/s, the $K_{c\ mid}$ values are adjusted using eq. 4, below:

$$K_{C\ mid} = K_{C\ mid}(tab) + [0.04(U_2 - 2) - 0.004(RH_{min} - 45)] \quad \text{..................(4)}$$

where:

$K_{c\ mid\ (Tab)}$ value for $K_{c\ mid}$ taken from Table 2,

U_2 is mean value for daily wind speed at 2 m, height over grass during the mid-season growth stage [m s^{-1}],

RH_{min} mean value for daily minimum relative humidity during the mid-season growth stage [%], and

h means plant height during the mid-season stage [m] for 0.1m < h < 10m.

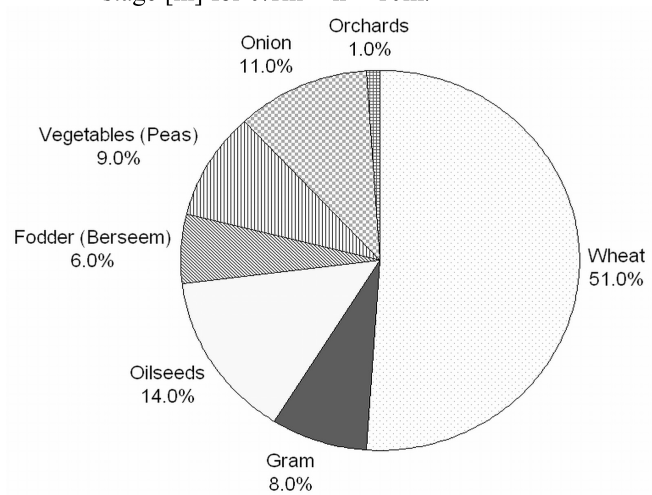

Figure – 2, Cropping Pattern for Rabi Season.

Crop Coefficient for the end of the Late Season Stage (Kc end): For specific adjustment in climates where RH_{min} differs from 45% or where U_2 is larger or smaller than 2.0 m/s, equation 5 can be used:

$$K_{c.end} = K_{c.end}(tab) + [0.04(U_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \quad (5)$$

$K_{c\ end\ (Tab)}$ value for $K_{c\ end}$ taken from Table-2.

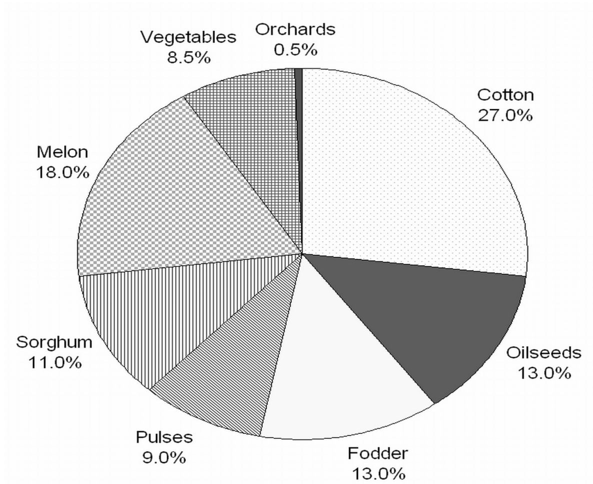

Figure – 3, Cropping Pattern for Kharif Season

RESULTS AND DISCUSSIONS

Comparison of ETo calculated from CROPWAT & spread sheet is shown in Figure 4. The results are comparable to each other with a variation averaging to 3% with a range from -3% to +8%. The discrepancy is quite small and is within acceptable range. This small difference can be attributed towards method of interpolation employed by CROPWAT

Figure 5 compares Reference Evapotranspirations (ETo) by Penman Monteith equation (spreadsheet and CROPWAT), Kimberly, Blaney Criddle, Hargreaves, & Pristley Taylor equations. The graph shows that ETo by Penman Monteith equation compares well with Blaney Criddle method and with Hargreaves equation, with an average difference of 11%, and 16%, respectively. Pristley-Taylor method, and Kimberly method differ by 45% and 42%, respectively from ETo computed by spreadsheet using Penman Monteith equation.

Thus in the absence of detailed climatic/radiation data required by Penman Montieth equation, simple but comparable methods of Blaney Criddle may be preferred, in this region.

Figure – 4, Comparison between Reference Evapotranspirations (ETo) calculated from FAO-56 (Spreadsheet) and CROPWAT.

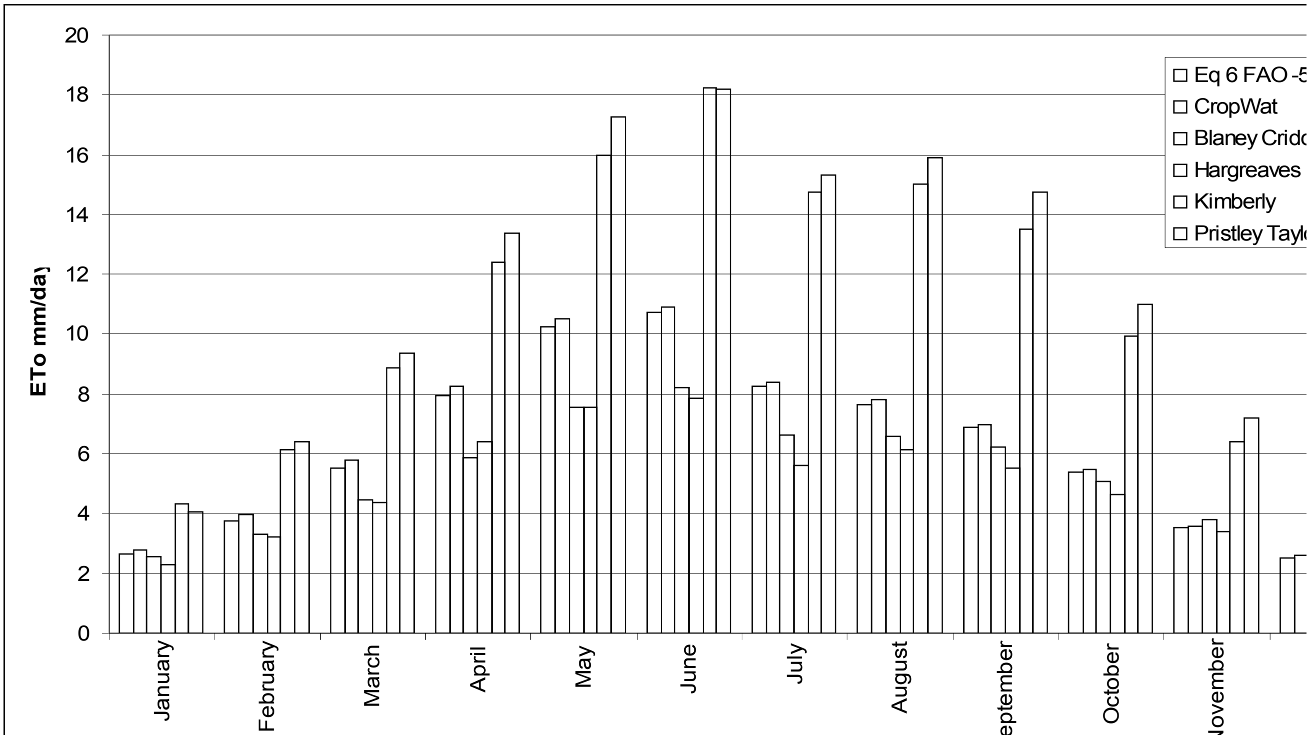

Figure – 5, Comparison of ET_o by various methods.

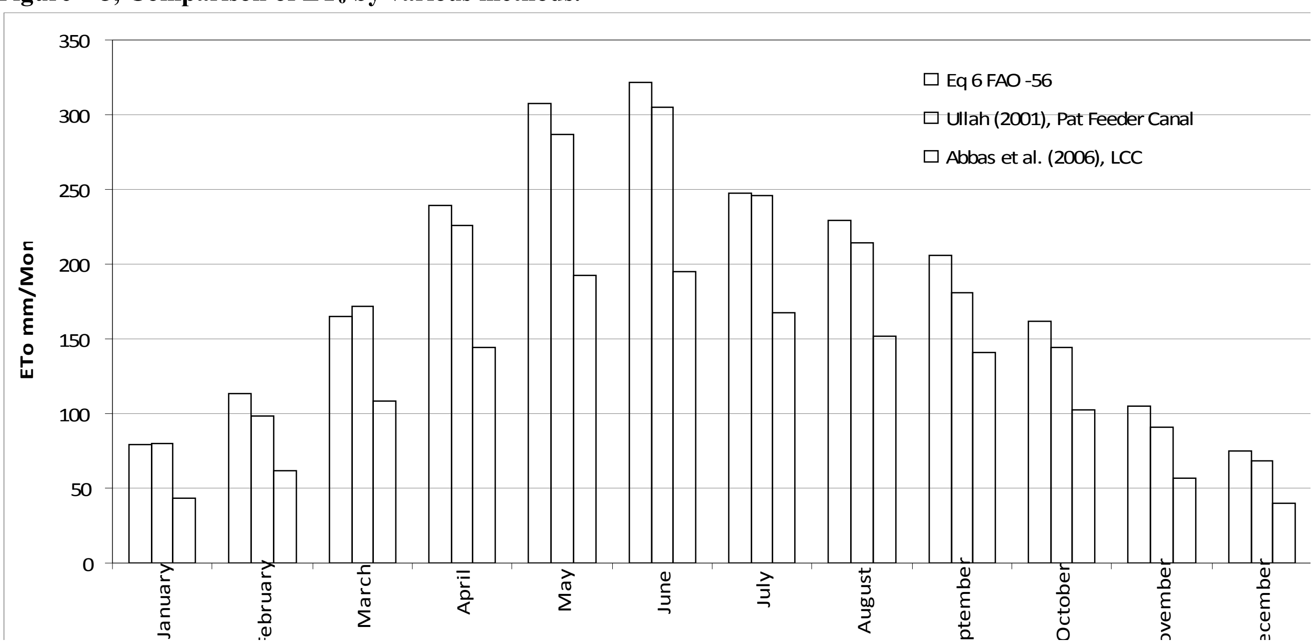

Figure – 6, Comparison of Crop Water requirement calculated under various studies.

Figure 6 compares the ET_o reported by two other studies, (Ullah *et al*., 2001) and (Abbas *et al*., 2006), for Pat Feeder canal and for Lower Chenab Canals, respectively. Pat Feeder canal is the neighbouring canal system to Kachhi command area (Figure-1), having similarly climatic setup. Lower Chenab Canal (LCC) is located about 500 km away from Kachhi Area, in Punjab province.

It is shown that the ET_o computed by this study (spreadsheet based) compares well with ET_o of Pat Feeder (Ullah *et al*., 2001) with a maximum difference of only 7%. ET_o of Lower Chenab Canal (LCC), however differs much, because of obvious reason of different climatic conditions in LCC and Kachhi areas.

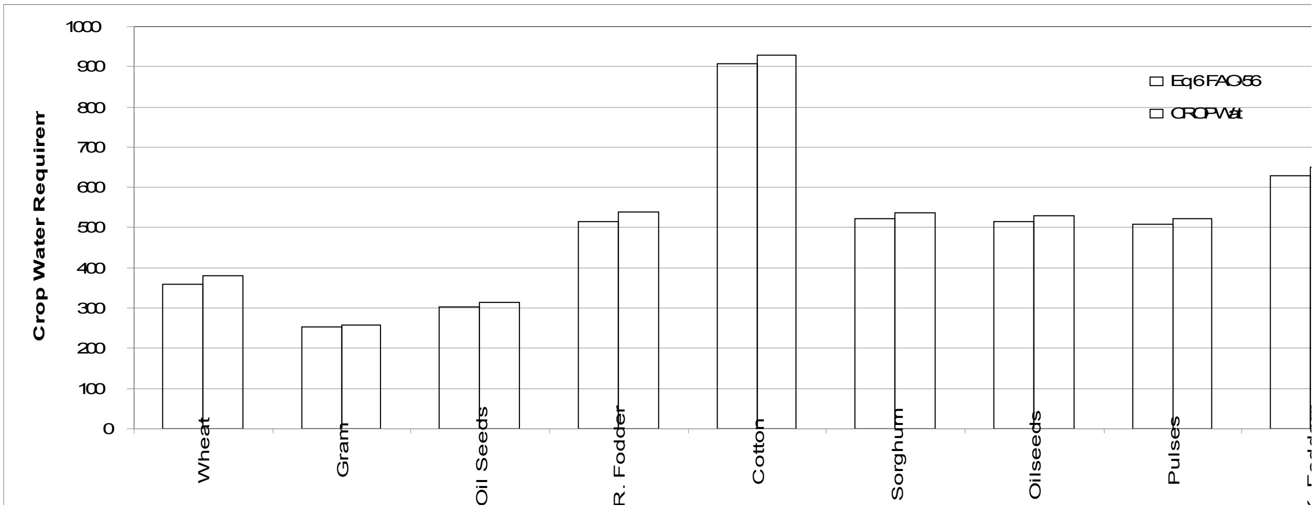

Figure-7, Comparison of Crop water requirement for various Kachhi Crops.

Table – 1, Mean Monthly Meteorological Data, Jacobabad [Ref. CimatWat]

Month	Temp Mean (°C)	Humidity, (%)	Wind Speed (Km/d)	Sunshine Hours	Effective Rainfall, mm
January	14	49	173	7	3
February	17.7	47	216	7.3	6.9
March	23.1	44	277	7.2	9.8
April	30	34	294	7.6	2
May	35.4	32	346	8.5	2
June	37.85	41	389	8.4	4
July	34.4	55	397	7.1	35.7
August	35.1	61	354	7.8	24
September	33.5	58	277	8.5	10.8
October	28.2	47	199	8.6	2
November	22.05	45	138	8.2	1
December	16.85	53	130	7.3	4

Table – 2, Crop Growing period and Crop Coefficient (Allen *et al*., 1998)

Crops		Crop Growth Stages (Days) and Kc Values				Total Length
		Initial	Development	Mid	Late	Days
Wheat		30	40	55	25	150
	Kc	0.40		1.15	0.30	
R. Oilseeds		30	40	50	30	150
	Kc	0.40		1.15	0.45	
Gram		30	40	50	30	150
	Kc	0.40		1.15	0.45	
Cotton		30	50	55	45	180
	Kc	0.35		1.1	0.5	
K. Oilseed		25	30	40	25	120
	Kc	0.30		1.10	0.5	
K. Fodder		20	30	30	10	90
	Kc	0.40		1.1	0.85	
Sorghum		20	35	45	30	130
	Kc	0.53		1.24	0.85	

After the spreadsheet based ET_o are verified by results of CROPWAT, and (Ullah *et al*., 2001), CWR for various crops is computed using computed crop coefficients. The CWR for wheat, gram, oilseed, cotton, and other crops are shown in Figure-7. Total water requirement for Wheat is estimated as 380 mm, while that for Cotton crop is 928 mm. Crop water requirement calculated by the spreadsheet matches well with that from CROPWAT, and the result differs only by 3 % from the cropwater requirements estimated/used by the feasibility report of the Kachhi Canal (Wapda, 2000).

Recommendations and Conclusion: The study successfully calculates reference crop evapotranspiration & crop water requirement using Penman Monteith equation, in easy to use spread sheet software. The tool developed can be used for other studies of similar nature.

The study concludes that Blaney Criddle method should be preferred if detailed data for required by Penman Monteith equation is not available.

The study can be used for optimization of the cropping pattern and can further be improved by estimation of crop water requirement using Lysimeter studies to be carried out in the study area. It can also be used to study the impacts of climate change on the crop water requirement.

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